RESEARCH DEPARTMENT

Considerations affecting the aperture and beam-tilt of u.h.f. transmitting aerials

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THE BRITISH BROADCASTING CORPORATION
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CONSIDERATIONS AFFECTING THE APERTURE AND BEAM-TILT OF U.H.F. TRANSMITTING AERIALS

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SUMMARY

Curves are presented showing how field strength varies with distance for idealized u.h.f. transmitting aerials of various apertures with different amounts of beam-tilt. From these curves conclusions are drawn regarding the maximum permissible aperture and the optimum beam-tilt for aerials erected on tall masts.

1. INTRODUCTION

For broadcasting applications the horizontal radiation pattern (h.r.p.) of the transmitting aerial is usually substantially omnidirectional, the gain depending on the vertical radiation pattern (v.r.p.), and hence on the length of the radiating aperture, usually expressed in wavelengths. Because the wavelength at u.h.f. is short, high gain aerials are practicable but may be expensive. In order to achieve a specified effective radiated power (e.r.p.) a compromise must therefore be reached between transmitter power and aerial gain. Typical aerials used at main stations have apertures of the order of 40 wavelengths, and such aerials concentrate most of the radiated power into a main lobe which is very narrow in the vertical plane; a 40λ aerial, for example, has a beamwidth between half-power points of only 1·3°.

If the horizon is viewed from a tall mast its direction is slightly below the horizontal; for a 1000 ft (300 m) mast, for example, the horizon angle is about 0·5°. Since the beamwidths of u.h.f. aerials are comparable with this angle, their main lobes must be tilted downwards in order to avoid a reduction of e.r.p. at the horizon.

The precise value of tilt angle depends on several factors. For example, if it is made exactly equal to the horizon angle only about half the power radiated by the aerial will be intercepted by the Earth's surface. A small increase in tilt angle would therefore appear to be advantageous, provided the e.r.p. at the limit of the service area is not reduced.

In order to study the relationship between aerial aperture and tilt angle, the average fields radiated by a number of different u.h.f. aerials placed 1000 ft (300 m) above ground have been calculated for distances up to the horizon. The calculations are based on the CCIR field strength/distance curves[1] and the transmitting aerials are assumed to have idealized vertical radiation patterns (to which good approximation can be made in practice). The calculations also enable the effects of mast deflexion to be assessed.

2. TRANSMITTING AERIAL REQUIREMENTS

An ideal transmitting aerial would provide uniform field strength at all distances up to the limit of the service area. Practical types of u.h.f. aerial cannot satisfy this requirement because of the rapid increase in path attenuation which occurs as the horizon is approached. Near the transmitter, however, path attenuation is less severe and an aerial providing uniform field strength in this region becomes feasible. It is therefore worth considering the shape which the v.r.p. of such an aerial must have in order to achieve this object.

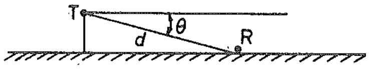

Fig. 1 - Transmitting aerial and receiving point

Fig. 1 shows a transmitting aerial T on a tall mast and a receiving aerial R situated at a small height above ground. Although the signal arriving at R is the resultant of direct and ground-reflected rays, it has been found experimentally that because of ground irregularities the average field strength near the transmitter is approximately equal to that of the direct ray. Thus if an isotropic* aerial were to be placed at T the average field strength at R would be proportional to $1/d$, and therefore to $\sin\theta$, where θ is the angle between the direction TR and the horizontal. It follows, therefore, that an aerial whose v.r.p. is proportional to $\operatorname{cosec}\theta$ will produce a uniform average field strength in the nearer parts of the service area, where earth curvature can be neglected.

The simplest form of u.h.f. transmitting aerial consists of a vertical array of similar tiers of elements, each carrying equal co-phased currents. Provided the inter-tier spacing does not exceed one wavelength the v.r.p. is given approximately by

$$E(\theta) \simeq \frac{\sin\psi}{\psi}$$

where

$$\psi = \frac{\pi A}{\lambda}\sin\theta$$

and A is the aperture of the aerial. This pattern is plotted as a function of ψ in Fig. 2. The envelope of the curve is given by $1/\psi$ and since this is proportional to $\operatorname{cosec}\theta$, it follows that the envelope represents the v.r.p. which gives uniform field strength in the nearer parts of the service area. Thus, if the zeros between the lobes could be filled to the level of the envelope, the v.r.p. would be approximately equal to cosecθ over a wide range of angles. Although this condition, often referred to as '100% gapfilling', is difficult to achieve in practice, a reasonably close approximation can be obtained by modifying the phases of the currents in the individual tiers.

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* An aerial radiating equally in all directions.

The maximum of the main lobe of the v.r.p. shown in Fig. 2 occurs at $\theta = 0$. Beam-tilt may be obtained by introducing a progressive phase shift over the whole of the aperture. The v.r.p. shown in Fig. 2 is then displaced sideways without change of shape.

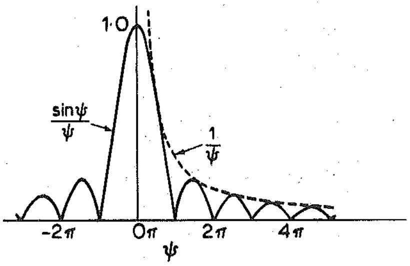

Fig. 2 - The vertical radiation pattern of a uniform array

For the calculations described in this report all the transmitting aerials were assumed to have sin ψ/ψ patterns 100% gapfilled below the horizontal (but not above), since reasonably close approximations to these v.r.p.s may be achieved in practice. As an example, the full line in Fig. 3 shows the idealized pattern assumed for a 40λ aerial with 0·5° of beam-tilt. Five aerials of apertures in the range 5 to 80 wavelengths were considered, with beam-tilts in the range 0 - 1½°.

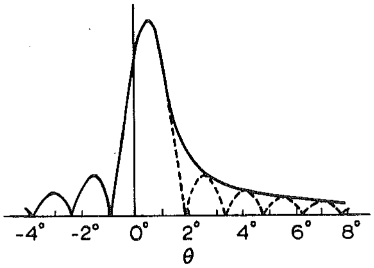

Fig. 3 - Idealized vertical radiation pattern

The example shows a 40λ aerial with a beam tilt of 0·5°

Increasing the aperture of an aerial increases its gain; this must therefore be taken into account. For the purpose of the calculations described in this report the aerials were assumed to have the gains stated in Table 1. These gains are typical values for practical aerials,* and include an allowance for gapfilling.

TABLE 1

Gains of idealized aerials

Aerial aperture	5λ	10λ	20λ	40λ	80λ
Gain relative to a λ/2 dipole	7 dB	10 dB	13 dB	16 dB	19 dB

3. THE CALCULATION OF FIELD STRENGTH

The variation of field strength with distance for idealized transmitting aerials mounted 1000 ft (300 m) above mean terrain† was calculated for distances up to the horizon, with the help of the appropriate CCIR field strength curve. These curves show the values of field strength, measured at a height of 33 ft (10 m) above ground, which were exceeded at 50% of the locations at which measurements were made;

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* It should be noted that the gain of an aerial consisting of a specific number of tiers may be less than that of an aerial whose aperture is the same number of wavelengths, because the inter-tier spacing of practical aerials is often less than one wavelength.

† Mean terrain level is defined[1] as the average ground level between 3 and 15 km from the transmitter, in the direction of the receiver.

they therefore represent the average field strength at this height. The curve for a transmitting aerial height of 1000 ft (300 m) is reproduced in Fig. 4 but with all values reduced by 4 dB to give the field strength exceeded at 70% of all locations.*

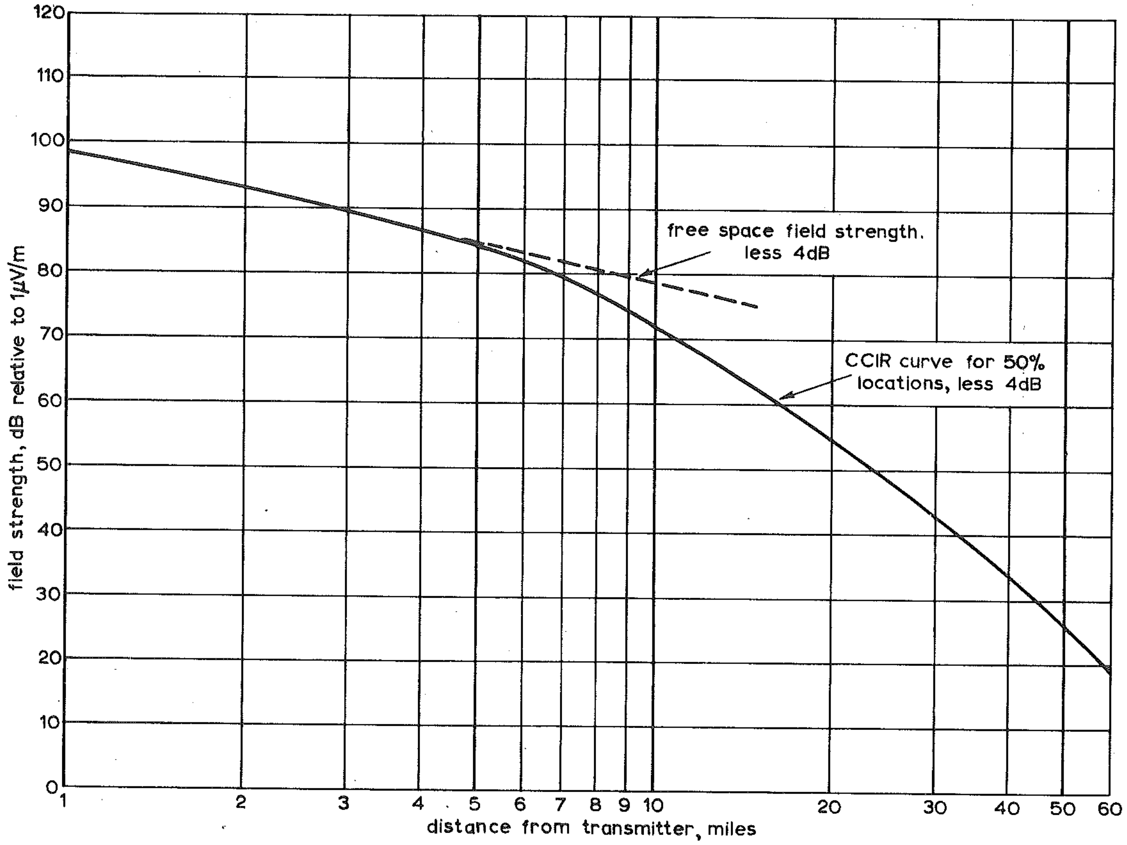

Fig. 4 - CCIR u.h.f. field strength curve

Fig. 4 is drawn for an e.r.p. of 1 kW and therefore gives the field strength which would be produced by a λ/2 dipole radiating 1 kW.

In calculating the field strength due to a more directional aerial radiating the same power, both gain and vertical directivity must be taken into account. It is therefore necessary to increase the values shown in Fig. 4 by the aerial gain, less a v.r.p. factor (expressed in dB) governed by the angle θ shown in Fig. 1. In calculating θ for distances greater than 5 miles (8 km) it is necessary to take earth curvature into account; this was done assuming the Earth's radius to be 4/3 times the true value, to allow for atmospheric refraction.

The results of the calculations for five different aerial apertures and four different beam-tilt angles are shown in Fig. 5. From these, further curves were deduced showing how field strength varies with beam-tilt angle; these are shown in Fig. 6.

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* Cover to 70% of locations is the standard adopted by the BBC to define the limit of the service area of a u.h.f. station. The 4 dB reduction corresponds to a local variation factor of 10 dB, which is typical for the U.K. The magnitude of this factor does not affect the relative merits of different types of aerials.

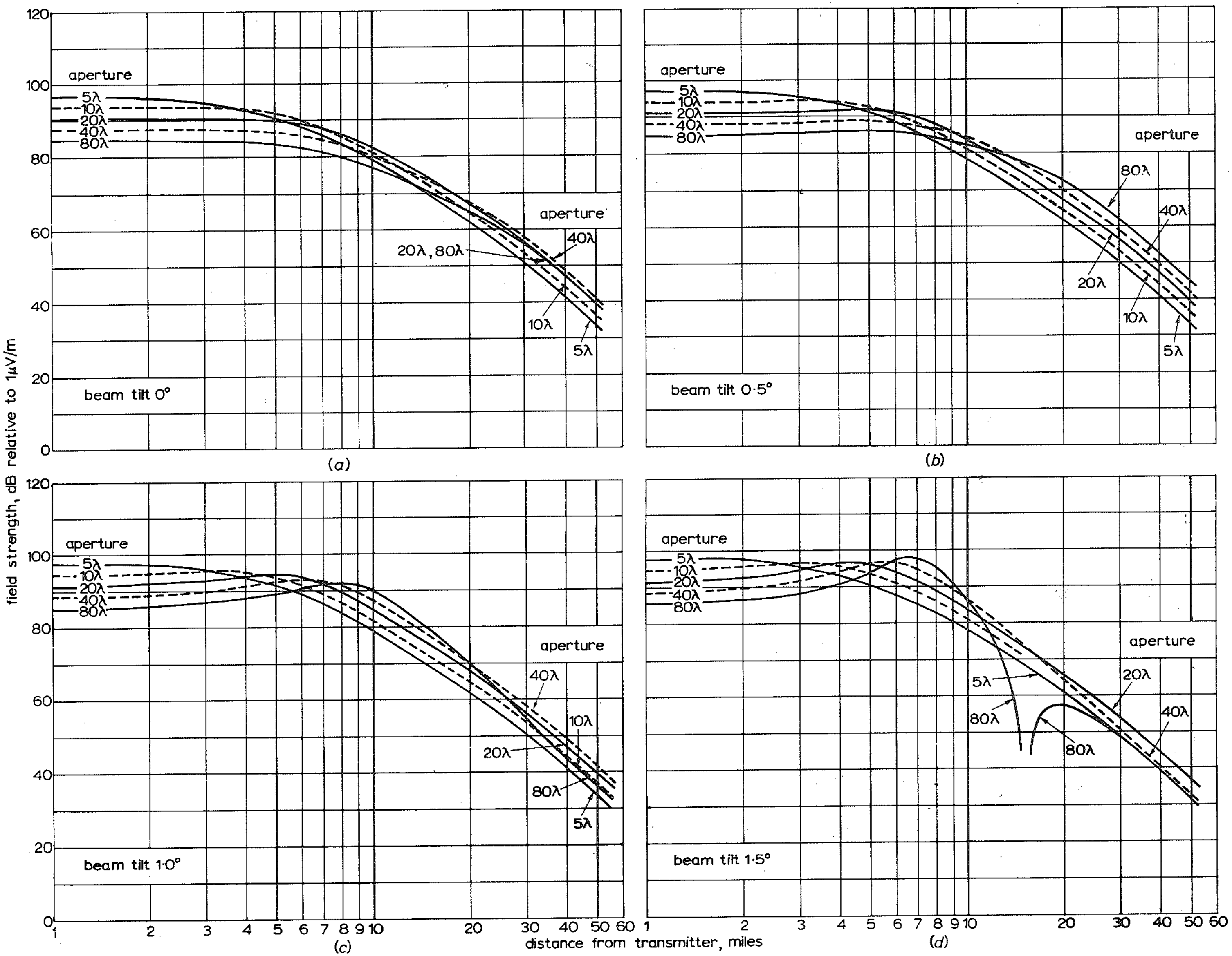

Fig. 5 - Field strength/distance curves for various idealized aerials mounted 1000 ft (300 m) above mean terrain

The field strengths are the values for 70% of locations and are based on the CCIR u.h.f. field strength curve. Height of receiving aerial 33 ft (10 m). Power input to aerial 1 kW

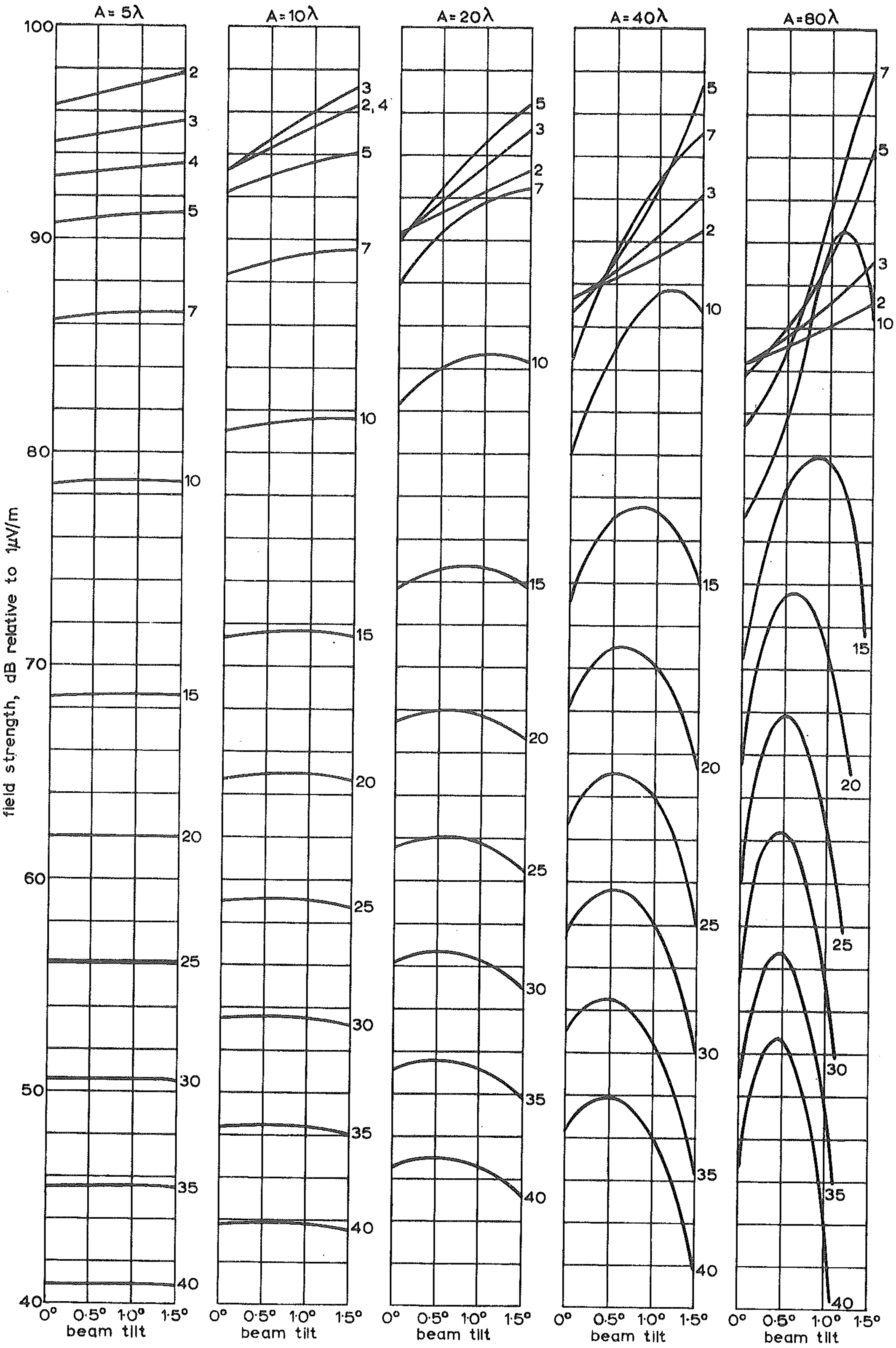

Fig. 6 - Variation of field strength with beam-tilt for idealized aerials of various apertures mounted 1000 ft (300 m) above ground

4. DISCUSSION

If an aerial 1000 ft (300 m) above mean terrain has a beam-tilt of 0·5° the maximum of its main lobe is directed at the horizon, and the resulting field strength curves have the form shown in Fig. 5(b). It will be seen that, at distances near the horizon, doubling the aperture increases the field strength by 3 dB, as would be expected. Close to the transmitter, however, doubling the aperture reduces the field strength by 3 dB, because the angular width of the radiation pattern has been halved. However, this reduction is not serious since the field strength near the transmitter exceeds the distant field strength even for the largest aperture considered.

If no provision for beam-tilt is made, the full gain of the larger-aperture aerials is not realized near the horizon because of the sharpness of their main lobes, as will be seen from Fig. 5(a). A similar effect occurs if the beam-tilt is increased beyond 0·5° (Figs. 5(c) and (d)), since the main lobes are now aimed too low. An enhanced field strength then occurs at the intermediate distance at which the main lobe is aimed. This is well illustrated by the curve for the 80λ aerial with 1½° of beam-tilt (Fig. 5(d)); here the maximum corresponding to the main lobe occurs at about 7 miles (11 km). The low field strength at 15 miles (24 km) is caused by the unfilled zero between the main lobe and the first upper secondary lobe; at greater distances the service is provided by this secondary lobe.

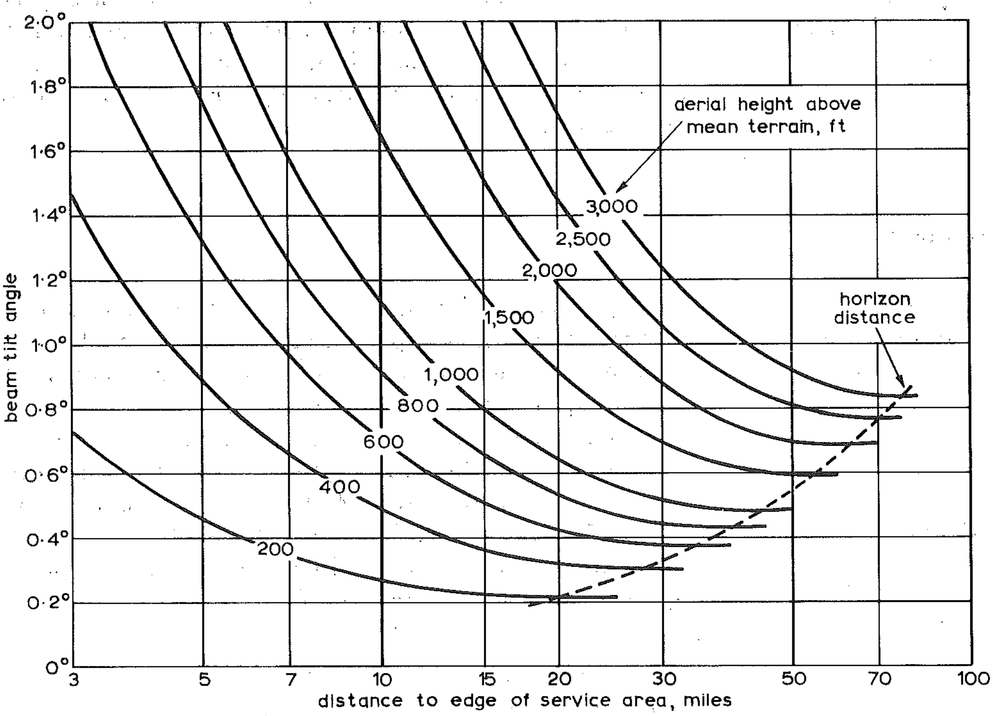

Fig. 7 - Optimum beam-tilt angles for aerials at different heights above ground

Calculated for Earth radius = 4/3 × true radius

The change in field strength which occurs with beam-tilt angle is more conveniently shown by the curves in Fig. 6. These curves also show how the change in field strength with tilt angle increases as the aperture increases, thus enabling the variations which are likely to occur in high winds (as a result of mast movement) to be assessed. It will be seen that the greatest variations occur at intermediate distances (7 miles (11 km) in the case of the 80λ aerial). These distances correspond to that region of the main lobe where the slope of the v.r.p. is particularly steep. It should be noted that with practical aerials even larger variations may occur at these distances because unless they are completely 'gap-filled' their v.r.p.s will be even steeper.

If the calculations had been repeated for transmitting aerials at other heights above ground, similar curves would have been obtained. We may infer that the field strength at large distances is always greatest when the aerial is as high as possible and the beam-tilt is equal to the horizon angle. At short distances an increase in aerial height causes a reduction of field strength; if the aerial height is doubled, a reduction of 6 dB occurs. This reduction is unimportant because, with the transmitter powers, aerial heights and apertures at present envisaged, the field strength in the nearer parts of the service area is considerably greater than the value considered necessary for an acceptable service. The reduction is far outweighed by the improvement which occurs in the more distant parts of the service area, where the field strength is much lower.

5. CONCLUSIONS

It has been shown that the beam of a u.h.f. aerial should normally be aimed at the horizon in order to obtain the maximum possible field strength at the more distant parts of the service area, together with reasonably uniform cover at closer distances. With very high aerials, however, the distance to the horizon may be so great that the effective radiated power may be insufficient to provide a service right up to the horizon; in such cases the main lobe of the transmitting aerial should be tilted below the horizon and aimed at the distance corresponding to the limit of the service area (about 35 miles (56 km) for the highest e.r.p.s at present envisaged). To enable the correct beam-tilt for aerials mounted at any height above mean terrain to be determined, reference may be made to Fig. 7.

If the correct beam-tilt angle is used, doubling the aperture of the aerial will increase the field strength in the distant parts of the service area by 3 dB. At the same time the field strength near the transmitter will be reduced by 3 dB because of the re-distribution of the radiated power; this decrease, however, is unimportant because the field strength in this region is relatively high. With higher-gain larger-aperture aerials the use of the correct beam-tilt becomes increasingly important because of their greater vertical directivity. For the same reason the permissible mast deflexion is reduced. Structural considerations therefore set an upper limit to the size of the apertures of practical aerials. With the type of mast construction normally used by the BBC, apertures of 40λ are practicable but greater apertures might necessitate special structural designs.

6. ACKNOWLEDGEMENTS

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7. REFERENCE

1. Technical Data used by the European V.H.F./U.H.F. Broadcasting Conference, Stockholm 1961.

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